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Regional aviation and the PSO system – Level of Service and social efficiency

Svein Bråthen ^{a,*}, Knut Sandberg Eriksen ^b^a Faculty of Logistics, Molde University College and Möreforskning Molde AS, Molde, Norway^b Institute of Transport Economics, Oslo, Norway

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ABSTRACT

The variation in Level of Service (LOS) and the objective of the Public Service Obligation (PSO) system raises the need for a method for determining the LOS based on social efficiency measures. Such a method is developed for assessing PSO and LOS in Norway. This paper presents and discusses this method, which may be relevant for other countries that employs similar supporting systems for air transport. A stepwise procedure is suggested for assessing PSO routes: Firstly, a framework for deciding upon LOS for air transport under PSO is presented. Secondly, we present a way of doing rough calculations of socio-economic profitability of PSO routes compared with best alternative transport. Finally, a model is presented which refines these calculations. One finding from the model simulations is that loosening the LOS restrictions on this type of regional aviation may lead to increased ticket prices and a reduced LOS. PSO restrictions may lead to a situation close to social optimum if wisely chosen. The most important step in future research is probably to test and refine the numerical model.

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1. Introduction

Many countries within the European Economic Area (EEA) are providing Public Service Obligation (PSO) air services, founded on Articles 16, 17 and 18 of Regulation (EEC) No 1008/2008. PSO is designed for scheduled services between any airport in the Community and an airport serving a peripheral region within its territory or on a thin route to any airport in its territory, including cross-border routes. The route should be vital for the economic and social development of the region served by the airport. If no airline is willing to provide a service under the conditions imposed, the government may restrict access to the route to a single carrier and award financial compensation to the carrier in return for compliance with the PSO. Over 90% of public service obligations are in respect of domestic services (Williams, 2010).

The public transport authority imposing the PSO is responsible for the judgement on the adequacy of air services for PSO. According to Williams (2010), in the Czech Republic, Finland, Greece, Ireland, Portugal and Sweden, national government departments administer air transport public service obligations, while in France,

Germany, Italy and Spain, administration is in the hands of regional authorities. In the UK, the Scottish Government is responsible for administering the routes operated from Glasgow and the respective regional authority for services provided in Orkney, Shetland and Western Isles, while in Wales it is the Welsh Assembly Government. In addition, Norway, Iceland and Switzerland adapt to this program, administered by national government departments.

This description indicates that it is largely up to the Member States to decide upon which routes are “essential air services” and to decide upon whether the Central Government or the Regional Governments should have responsibility for the PSO tenders. This has led to a certain degree of diversity in PSO practice.

Norway has the largest number of PSO routes (around 60), followed by France with around 40. Spain, Portugal and Scotland have 10–12 routes each. The average legs vary between about 600 km (France) and 200 km (Norway). The average seating capacity varies between larger aircraft of 110–70 seats (Portugal and France), 50–35 seats (Spain, Sweden and Germany) while Scotland are using smaller aircraft down to 10–15 seats. Norway has 15 seats as minimum, whereas most aircraft are 39 seats. The average subsidy level in Germany is around EUR 120 per passenger, for Norway, Sweden and Scotland it is around EUR 60 per passenger, while France and Portugal had subsidies of slightly above EUR 20 per passenger.

* Corresponding author.

E-mail addresses: svein.brathen@himolde.no (S. Bråthen), knut.sandbergeriksen@toi.no (K.S. Eriksen).

Williams and Pagliari (2004) presented and discussed how different European Economic Area member states have adopted and made use of the PSO mechanism in air transport. This study gives a comprehensive overview and provides a good support for understanding the variation with respect to how the PSO regime is applied. This study suggests that this variation may be larger than optimal in the sense that the use spans from thin routes in remote areas (like Scotland and Norway), via busy tourist routes to islands and to routes where surface transport appears as a viable alternative.

This variation in Level of Service (LOS) and the objective of the PSO system raises the need for a method for determining the LOS based on social efficiency measures. Such a method is developed for assessing PSO and LOS in Norway. This paper presents and discusses this method, which may be relevant for other countries that employ similar supporting systems for air transport. USA has its PSO-like Essential Air Services Program, which was firstly assessed by Reynolds-Feighan (1995). Mettrass-Mendes et al. (2011) discuss the National Airport Policy program (NAP) in Canada. While the PSO and EAS tender out contracts in a competitive bidding system, Canada goes further in tailoring the support to specific needs, like shipments of food, medication, mail, tools and equipment and medical requirements. The support is also assigned to specific travel purposes, like medical care. USA does also have a smaller program (Small Community Air Service Development Grant (SCASDG) program), which supports existing services with respect to economic sustainability. Wittman (2014) gives a further description and assessment of SCASDG.

The rest of the paper proceeds as follows: Section 2 presents the PSO system, including the tendering procedure. Section 3 presents the LOS criteria developed for the Norwegian PSO for air transport and how they can be used. Section 4 discusses a model for quantifying social efficiency for PSO routes. Section 5 concludes the paper. The paper gives references to relevant literature throughout, and hence no separate literature review is given.

2. The PSO-system

2.1. How does PSO work?

If commercial operation of the regional aviation network is not feasible, some sort of financial support is necessary to maintain the route pattern that the Norwegian Ministry of Transport and Communication (NMTC) wants to support. Previously, air services for the remote regions were sourced from available operators. These were regulated by annual block grant contracts, where NMTC would then cover the deficit of the local operator for running the specified service.

The system of Public Service Obligation (PSO) was initiated by the European Commission to secure efficient competition among operators and an acceptable service supply to air travellers in the regions to the cheapest possible cost. This is regulated in the [European Parliament Regulation number 1008/2008](#).

The standard of the route supply may be characterised among other things by:

- Number of round trips per day.
- Seat capacity per day.
- Route pattern (including number of stops at different airports and time schedules).
- Number of days per year with no service.
- Size of aircraft.
- Emissions to air of specified substances.
- Comfort factors.
- Airfares.

The winner of the bid is normally the bidder who claims the lowest subsidy for operating a specific route area for a period of 4–5 years as a rule.

It is also possible to combine more factors in the winning criteria as a package where a specific weight may be placed on each factor – or all factor may be judged together, the amount of subsidy being the most important factor. A minimum (maximum) limit may be set for the most important factors.

The general principles for PSO are listed in the European Parliament Regulation number 1008/2008, Article 16. PSO can be offered on thin routes both within and between countries, and we refer to this document for details. One element that can be mentioned from Article 16.3, is that if alternative modes of transport (rail transport is mentioned in particular) can be used on the same origin–destination pair with a travel time of less than three hours, then the necessity and the adequacy of the PSO service shall be assessed. In practice, the Member states have a relatively large degree of freedom with respect to when a PSO service should be offered, also with respect to the definition of a ‘thin route’. Bråthen (2011) summarizes some experiences with respect to air transport PSO (and EAS).

The main objective of this paper is to provide guidance on a generic way of assessing whether a PSO air service should be provided at all, and if yes, how it should be designed with respect to Level of Service (LOS) including departure frequencies and airfares.

2.2. PSO and commercial aviation

Commercial operation is of course in many cases the most desirable solution, but in the sparsely populated regions of Norway, it is normally not feasible except for the trunk routes (served by Boeing 737/600–800 or similar) or denser single legs within the short track network (served by Bombardier Dash 8/100–400 or similar).

If commercial operation is possible, airfares will usually increase and the number of daily flights (frequencies) will go down, assuming thin markets with no competition. This has happened in several cases where a route area is split into one commercial part – usually a single leg – and one part that still will need PSO subsidies. Some of the thin commercial routes that have previously been a part of the PSO network have been subjected to political discussion because of the reduced LOS and higher airfares.

There is however another option. For NMTC (or any responsible PSO authority) it is possible to design the tender so that one may have a zero bid within the PSO framework. This means that the airline is protected from competition during the PSO period, but no subsidies are paid.

3. Level of service (LOS)

One main point of departure for defining an efficient PSO network is to identify a level of air transport services (LOS) that balances the social need for accessibility with the costs of providing the PSO services. It is a matter of discussion whether a PSO service on a certain route should be provided at all, and if so, what LOS will serve the needs of the local community.

It is not straightforward to define a LOS based on a perception of a minimum transport standard for remoter regions. The international literature on this issue is scarce. Currently, it appears to be a matter for *ad hoc* decision making by national policy makers.

Clearly, the concept “transport standard” has both political and economic implications. One could define constraints related to e.g. maximum travel time to bigger cities, minimum available time spent at important destinations like a capital or a regional centre during a day trip. Access to hospitals and to airports with

international connections could be other examples. Such criteria will most certainly give constraints for the design of the transport network, and it will be important to search for the most efficient solutions to fulfil the given criteria. At the same time, fulfilment may entail severe economic costs, e.g. to serve remoter small communities with expensive infrastructure. It is therefore appropriate to assess the socio-economic consequences of defining such criteria.

Thune-Larsen et al. (2014) and Bråthen et al. (2015) discuss points of departure for defining such criteria for PSO air services in Norway. The discussion is partly based on Trafikverket (2013), which has derived some criteria for Swedish regional air transport. The criteria should be adapted to different needs among the regions, and a certain amount of pragmatism is needed. For example, criteria stating a possibility for day trips to the capital of Oslo for a full day of work may be applicable for regions in southern Norway, whereas the same criterion is likely to be impossible to fulfil for remoter regions in Northern Norway. This is a generic challenge for many countries. In the USA within the Essential Air Services program (EAS), one criterion for providing a subsidised route, is e.g. a certain distance (at least 70 miles) to the nearest larger city (Mettrass-Mendes et al., 2011), which will inevitably give varying accessibility from the regions to Washington DC and other metropolitan areas.

One purpose of defining such criteria is to avoid *ad hoc* decisions that may cause a LOS that varies between regions, give little predictability and leave room for expensive transport services based on local political pressure and subsidised by the State.¹ The first step will now be to define a set of criteria. The main criteria that was set out for Norway and Sweden, were as follows:

- Accessibility to the Capital.
- Access to an airport with international services.
- Access to advanced health care (a larger hospital).
- Access to the County administration.

The accessibility is considered from the communities connected to a local airport and to the destination. A weighted measure of travel time for the citizens in the area is applied. The criteria is defined with travel time duration, for some criteria the length of stay at the destination, both according to a full ('green') standard and a minimum satisfactory ('yellow') standard. A detailed description is given in Table 1.

The criteria are not weighed, and all criteria may not be relevant for all routes. An example may be a case where a local airport connects with e.g. several larger airports with international services. A LOS that does not fulfill these criteria is termed as a 'red standard'.

The next step will now be to assess the LOS level according to these criteria, for relevant transport alternatives. Fig. 1 shows an example of transport standard criteria fulfilment for an imaginary remoter community. The criteria fulfilment is arbitrarily, for illustration purposes only.

For this imaginary local community, surface transport will in essence not meet the LOS criteria. There is also a potential for improvement of today's transport, which could be a PSO air service.

The third step will now be to combine the LOS standard assessment above with a socio-economic assessment in a conceptual model. As a point of departure, a rather straightforward calculation of generalized transport costs with air transport (G_A) and the cheapest surface transport mode (G_S) can be made for

comparison. Generalized transport costs consist of payable costs (fares, tolls), travel time costs and vehicle operating costs (for road transport). The data needed is estimation of the value of travel time savings, travel distance, travel time and payable costs per transport mode for the different transport alternatives, together with origin-destination matrices. If $G_A > G_S$ then the LOS of PSO air service should be reduced, or the PSO service should cease operations altogether. If $G_A < G_S$ then one should assess if the costs of having to use surface transport justifies the PSO subsidy level (S). If $(G_S - G_A)/S > 1$, then the cost savings/subsidy ratio indicates that the added costs of using the surface transport exceeds the air transport subsidy level, which give reasons to provide the subsidised service. On the other hand, if $(G_S - G_A)/S$ is clearly < 1 , then there is a good indication that the LOS of the PSO service cannot be justified for economic reasons in terms of travel cost savings. The calculations can be made iteratively to approach whether a PSO service should be offered, and if so, at what LOS. A model like the one described in Section 4 can also be applied. Fig. 2 summarizes this procedure in a conceptual model.

The model offers an interplay between accessibility criteria and assessments based on generalized travel costs. If it is clearly so that $G_A < G_S$ (which is the situation in most cases in practice) then one could go straight to box 4 and iterate or model the best LOS for air transport that satisfies both the $(G_S - G_A)/S$ -criterion with the accessibility criteria as constraints. One could also rank the PSO routes based on the $(G_S - G_A)/S$ -ratio. We would like to mention that slot capacity constraints are not included in the model (this is pointed out as an issue in PSO services in the UK by Merkert and O'Fee, 2013), but this element can easily be added. This issue could be of importance for future research because the slot constraints coincide with demand peaks and the constraints will therefore affect accessibility both to larger cities and to international flights, at a cost for the affected regions. Hence, it could be of interest to model the PSO system with and without such constraints and to compare the socio-economic outcome. This could inform a decision-making process in order to consider possibilities for slot expansion. Such constraints are non-existent in many countries with PSO, like in Norway, but it may be an issue at the busiest airports in European metropolitan areas, like London Heathrow.

The fifth step is to do the calculations in the conceptual model. Such calculations are carried out for all the PSO routes in Norway, and the work is reported in Thune-Larsen et al. (2014) and Bråthen et al. (2015). We will now present the assessment procedure for a selection of routes in southern Norway. These PSO routes are Førde-Bergen, Sogndal-Bergen and Fagernes-Oslo, which can be seen on the map in Fig. 4. Table 2 shows the calculations, summarised to average numbers per passenger. The aircraft operating costs are calculated, based on a model from Janic (2000).²

The cells with no numbers indicate that this cost element is not relevant for the transport alternative in question. The PSO subsidies are the difference between the calculated aircraft costs per passenger (results from the Janic (2000) model, where costs per seat with the actual aircraft load factor is used) and the actual average airfare.

Table 2 shows that the route Sogndal-Bergen has the highest $(G_S - G_A)/S$ ratio, whereas Fagernes-Oslo has the lowest score. For this route, the generalized cost saving with air transport is less than EUR 5, whereas the subsidy per passenger is slightly under EUR 375. From these calculations, the return is EUR 0.01 per EUR in

¹ It could be argued that the local air services should be provided by the regions, to ensure a coordinated prioritization of regional public spending.

² The model: $C(n, d) = 7.934 \cdot n^{0.603} \cdot d^{0.656}$ where $C(n, d)$ is average cost per flight/n aircraft seat capacity/d length of flight in km. The model fits well with Norwegian PSO cost data, with an average deviation of 2%, measured on 20 PSO routes.

Table 1
Example of criteria for defining LOS of air services.

Criteria	Green standard	Yellow standard
Access from a local airport to the Capital and an international airport(1)	Monday to Friday: Latest arrival to the Capital's airport at 8.30 am, after a total travel time of max 3 hours from home. One could stay in the center of the Capital between 10 am and 4pm. Earliest return flight from the same airport to the local airport departs at 5 pm. Max 4 hours travel time to home.	Monday to Friday: Latest arrival to the Capital's airport at 10 am, after a total travel time of max 4 hours from home. One could stay in the center of the Capital for 6 hours. Earliest return flight from the same airport to the local airport departs at 3 pm. Max 5 hours travel time to home.
Access from a local airport to an international airport(2)	Monday to Friday: Latest arrival to an airport with international services at 8.30 am, after a total travel time of max 3 hours from home. Earliest return flight from the same airport to the local airport departs at 5 pm. Max 4 hours travel time to home.	Monday to Friday: Latest arrival to an airport with international services at 10 am, after a total travel time of max 4 hours from home. Earliest return flight from the same airport to the local airport departs at 5 pm. Max 5 hours travel time to home.
Access to advanced health care (3)	All week: Latest arrival to the hospital at 10 am with the earliest start at 3 am from home and max 3 hours travel time. Earliest return flight from the hospital's closest airport to the local airport departs at 4 pm. Max 4 hours travel time to home.	Monday to Friday: Latest arrival to the hospital at 10 am with the earliest start at 3 am from home and max 4 hours travel time. Earliest return flight from the hospital's closest airport to the local airport departs at 4 pm. Max 4 hours travel time to home.
Access to the County administration (4)	Monday to Friday: As for Criterion 3	As for Criterion 2.

Transport alternatives	Criteria			
	1	2	3	4
	Access to the Capital	Access to an international airport	Access to advanced health care	Access to the County administration
Today's transport (could be a PSO air service)				
Surface transport (in some cases equal to today's transport)				
PSO air transport, alternative LOS (the alternatives 1...n)				

Fig. 1. Illustration of LOS criteria fulfilment.

subsidies for Fagernes-Oslo, and correspondingly EUR 0.16 on Førde-Bergen and EUR 1.95 on Sogndal-Bergen.

Fig. 3 shows how these three routes meet the LOS criteria.

Surface transport gives at least a minimum satisfactory LOS for Fagernes-Oslo, but not for the other two. For Førde-Bergen, the alternative route with surface transport to Florø and air from there will give a minimum satisfactory LOS. Both these PSO routes to Oslo and Bergen respectively, give a very low $(G_S - G_A)/S$ ratio. The route between Sogndal and Bergen gives a minimum LOS when going by surface and air via Florø. However, the $(G_S - G_A)/S$ ratio is more than sufficient to justify a direct PSO service to Bergen.³ The County Administrations have either good access by surface transport or they are located in places without an airport.

When it comes to dimensioning of the LOS for the PSO service, one should iterate towards a minimum 'yellow' standard and assess $(G_S - G_A)/S$ ratio. In these three cases, there is a clear conclusion that

Førde-Bergen and Fagernes-Oslo should be closed as PSO services. The PSO service between Sogndal and Bergen should be maintained and perhaps even be considered for upgrading with a higher departure frequency.

4. A model for determining social efficiency

4.1. PSO and social efficiency

How do PSO services affect social efficiency? To be more specific how can the central and local governments secure the highest possible social efficiency of the PSO arrangements?

It seems clear that profit maximisation may strongly reduce the amount of subsidies. However, this may not be socially efficient. How do technical limitations concerning e.g. aircraft, runways and landing conditions affect the solutions? How is regional welfare affected by the existence of PSO arrangements alongside commercial aviation?

³ Assessment of the potential for a non-PSO service gave a too high airfare to become commercially viable.

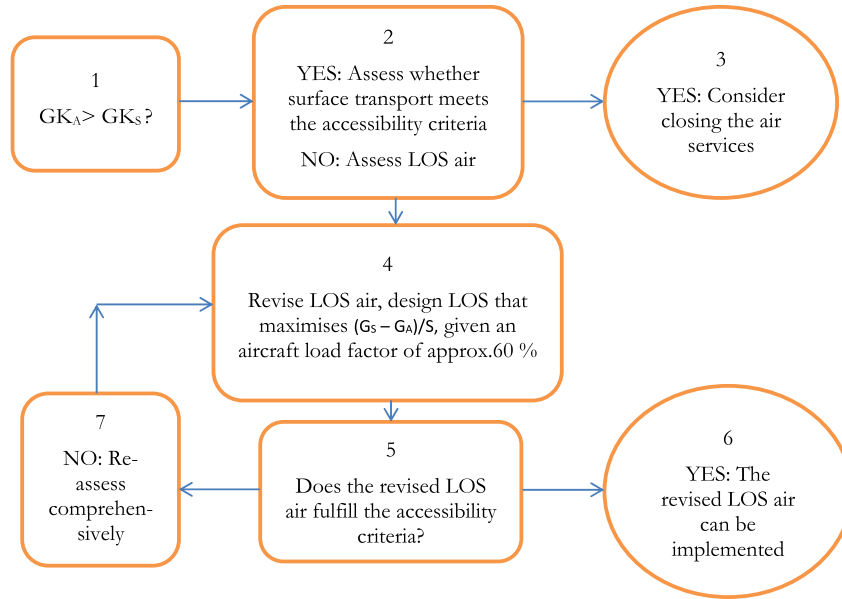


Fig. 2. Assessment of PSO services.

Table 2
Generalized costs, aircraft operating costs, air fare revenues and PSO subsidies, in EUR (2014, rounded). PSO routes Førde-Bergen, Sogndal-Bergen and Fagernes-Oslo.

Transport alternative	Førde-Bergen		Sogndal-Bergen		Fagernes-Oslo	
	Air	Surface	Air	Surface	Air	Surface
Travel time centre-centre (hours), including airport shuttle and ferries	1.45	3.33	1.55	4.28	1.33	3.10
Value of travel time:	57	128	60	164	51	119
Payable costs excl. airport shuttle:						
• Airfare	60	–	74	–	56	–
• Road tolls, ferries	–	14	–	18	–	4
• Vehicle driving costs	–	30	–	41	–	32
Costs to/from the airports	44	–	44	–	44	–
SUM G_A and G_S	161	172	178	223	151	155
Aircraft costs and PSO subsidies, per passenger, one way:						
Aircraft costs	127		97		467	
PSO subsidies (S)	67		23		411	
Generalized cost saving/subsidy ratio: ($G_A - G_S$)/S, per passenger	0.16		1.95		0.01	

	Criteria			
	1	2	3	4
	Access to the Capital *)	Access to an international airport	Access to advanced health care	Access to the County administration
Førde-Bergen				
Surface				
Surface and air via Florø				
LOS air Førde-Bergen				N/A
Fagernes-Oslo				
Surface				
LOS air Fagernes-Oslo				N/A
Sogndal-Bergen				
Surface				
Surface and air via Florø				
LOS air Sogndal-Bergen				N/A

Fig. 3. LOS criteria for 3 routes (*) Access to the Capital is served by direct routes to Oslo.

4.2. The model

In attempting to give some answers to these questions, we will apply a model for optimising route operations developed by Eriksen and Minken (2005). It may be seen as a way of addressing the issues in Box 4 in Fig. 2 above. The model was developed to be a tool for NMTC in designing PSO tenders and deciding among the bidders.

The model is a semi linear model based on the concept of a route operation. This describes the production of air services in a route area for a specific period of time in which the aircraft return to the starting point each day (or similar period).

The cost function of the model is based on an analytical approach, which is a combination of a statistical and an engineering approach.

The average airfares (ticket prices) are calculated from operators' travel statistics and from air travel surveys that contains information about the distribution between full-fare and discounted fares.

The overall model consists of four sub-models:

- The cost model
 - Describes the production of an air service and the related cost structure. Passenger demand for travel is described in a simple way.
- The profit model
 - Profit is maximised under economic and technical restrictions.
- The social surplus model
 - Operator's profit in addition to the consumers' benefit minus costs and plus public tax revenue.
- The route optimisation model
 - The alternatives and combinations must be specified for each case. Thus this part of the model is not yet developed.

The model is presented in more detail in the Appendix and explained in Eriksen and Minken (2007).

There are two main cases:

1. The size of aircraft is given. The air fares (ticket prices) and frequencies are optimised and thus the number of aircraft, private profit and social surplus may be maximised in turn. The number of aircraft may be indivisible in the main case. But it may be possible to share aircraft between (neighbouring) route areas to obtain a better utilisation of the fleet.
2. Alternatively the ticket prices are given. The size of the applied aircraft may then be optimised to maximise profit or social surplus. The number of aircraft will normally be indivisible here as well, but may also be shared between route areas.

To summarise, the objectives of the model are to:

- calculate the expected lowest bid - given aircraft size, frequencies etc.
- calculate the most profitable bid for the operator and for society.
- calculate highest pay-back to society per € or NOK.
- calculate the best bid for a given amount of subsidies.
- optimise a given amount of subsidies between route areas.

The two last points demand repeated calculations with the model.

4.3. Numeric examples

There are 15 PSO route areas in Norway. The North Western

coast of Norway is used as an example here, and the structure is illustrated in Fig. 4. This is a route area consisting of four local airports and two central ones: Ørsta/Volda, Sandane, Førde, and Sogndal in addition to Oslo and Bergen as end destinations (the two latter ones are used as examples in Section 3). The route plan consists of 8 different legs and 14 roundtrips.

The reason for selecting this specific route area was that even if it consists of a quite complicated pattern of legs and roundtrips it is not among the most complicated route areas in the country, and therefore it is a transparent case for testing the model. Furthermore, it consists of routes that have a potential to be commercially profitable as well as routes with very low occupancy rates of around 30%.

We aim to compare the “present” (2014) situation of the route area with parallel situations where profit of the operator or social benefit is maximised, asking the following questions:

- What happens if private operators are allowed to maximise profits?
- How can social benefits be maximised?
- Can restrictions contribute to increased social efficiency?
- What happens to regional equity?
- Can reorganising of route areas contribute to social efficiency?

In the main case the size of aircraft remains constant, while profits and social benefits are maximised respectively. Ticket prices and number of aircraft may vary.

Table 3 shows that with profit maximisation, the number of round trips is reduced, and the number of aircraft is reduced from three to two. The ticket price increases by 40%. Private profit turns out to be positive, and the negative social benefit is slightly improved when comparing with base case.

Table 4 shows that the number of aircraft is reduced even more in the case of shareable aircraft.

Table 5 shows that with profit maximisation and fixed airfares, private profit has become positive with a good margin. However, social benefit max may lead to better social benefit, but still it comes out as negative as compared with base case. The profits are also negative if social surplus is maximised.

Fixed airfares as shown in Table 5, will lead to reduced size of both in the profit maximisation case and in the social benefit maximisation case. The number of roundtrips increase and the deficit of the operators and the social benefit have decreased, while still negative.

However, Table 6 shows that with fixed airfares and divisible



Fig. 4. The North West route area.

Table 3
Profit maximisation and social benefit maximisation with indivisible aircraft number and fixed aircraft size. EUR (2014).

Discrete aircraft		Roundtrips	Size of aircraft	Aircraft	Ticket price	Profit	Social benefit
			Seats	No	Euro	Euro	Euro
Base case	Abs	14,0	38	3,00	112	–26101	–33252
	Pct	100%	100%	142%	100%	304%	211%
Profit max	Abs	11,9	38	2	158	4939	–29157
	Pct	85%	100%	67%	141%	–19%	88%
Soc benefit max	Abs	13,1	38	2	106	–3279	–5850
	Pct	94%	100%	67%	95%	13%	18%

Table 4
Profit maximisation and social benefit maximisation with divisible aircraft number and fixed aircraft size. EUR (2014).

Shared aircraft		Roundtrips	Size of aircraft	Aircraft	Ticket price	Profit	Social benefit
			Seats	No	Euro	Euro	Euro
Base case	Abs	14,0	38	2,11	112	–8572	–15723
	Pct	100%	100%	100%	100%	100%	100%
Profit max	Abs	6,6	38	1,00	169	24368	–14673
	Pct	47%	100%	33%	151%	–93%	44%
Soc benefit max	Abs	11,9	38	1,81	103	–3953	–1480
	Pct	85%	100%	86%	92%	46%	9%

Table 5
Profit maximisation and social benefit maximisation with indivisible aircraft number and fixed airfares. EUR (2014).

Discrete aircraft		Roundtrips	Size of aircraft	Aircraft	Ticket price	Profit	Social benefit
			Seats	No	Euro	Euro	Euro
Base case	Abs	14,0	38	3	112	–26101	–33252
	Pct	100%	100%	100%	100%	100%	100%
Profit max	Abs	20,3	26	3	112	–9259	–18153
	Pct	145%	68%	100%	100%	35%	55%
Soc benefit max	Abs	20,3	25	3	112	–6909	–15925
	Pct	145%	66%	100%	100%	26%	48%

Table 6
Profit maximisation and social benefit maximisation with divisible aircraft number and fixed airfares.

Shared aircraft		Roundtrips	Size of aircraft	Aircraft	Ticket price	Profit	Social benefit
			Seats	No	Euro	Euro	Euro
Base case	Abs	14,0	38	2,11	112	–8572	–15723
	Pct	100%	100%	100%	100%	100%	100%
Profit max	Abs		62				
	Pct		164%				
Soc benefit max	Abs		75				
	Pct		197%				

aircraft numbers we get infeasible results, as the optimal size of aircraft is out of range i.e. too large for the STOL airports.

Lastly, Table 7 shows that if there are no restrictions profit maximisation leads to the doubling of airfares and reduced aircraft size and reduced number of roundtrips. Max of social benefit here gives a solution that is out of range.

It should be noted that firm conclusions might not be drawn based on this numeric example for just one single route area. However, from Tables 3–7 it can be argued that the best solution for the routes in this example could be shared aircraft, 12 round trips/day and a modest level of PSO subsidy.

5. Findings, conclusions and directions for future research

Merkert and O'Fee (2013) stated that from the national government and EC, systems for more transparency and better incentives to the operators should be provided. They also recommended to augmenting the EC's role as a watchdog to ensure

that PSO are fulfilling the intentions in the EC 1008/2008 regulations. This paper does not aim to discuss the operator's incentives, but it provides a framework and a model for defining and assessing the minimum LOS requirement for a transport standard for remoter regions. The paper also advises on a simple assessment method of the economic viability for a PSO service. Both these elements may be refined, but they should contribute to more transparency along the lines that Merkert and O'Fee (2013) suggest.

Some conclusions from the modelled examples could be:

- Constant aircraft size:
 - Profit max leads to positive profits and 40–50 pct. increase in ticket prices. Social benefit will increase slightly.
 - Social benefit max leads to a small drop in ticket prices and increases in profits and social benefits.
- Continuous aircraft numbers lead to larger effects than with integer aircraft numbers.

Table 7

Profit maximisation and social benefit maximisation with divisible aircraft number and no restrictions.

Shared aircraft		Roundtrips	Size of aircraft	Aircraft	Ticket price	Profit	Social benefit
			Seats	No	Euro	Euro	Euro
Base case	Abs	14,0	38	2,11	112	–8572	–15723
	Pct	100%	100%	100%	100%	100%	100%
Profit max	Abs	6,7	27	1,00	198	26084	–26192
	Pct	48%	72%	47%	176%	–304%	167%
Soc benefit max	Abs		88				
	Pct		231%				

- Constant ticket prices:
 - Profit max leads to increased profits and social benefits, but still negative. Optimal aircraft size is reduced.
 - Social benefit max leads to increased profits and social benefits. Optimal aircraft size is reduced.
- Continuous aircraft numbers lead to increased aircraft size.

Overall, it seems that loosening the LOS restrictions on this type of regional aviation may lead to increased ticket prices and a reduced LOS. PSO restrictions may lead to a situation close to social optimum if wisely chosen.

However, PSO and commercial aviation in two neighbouring route areas may lead to equity problems and protests as difference in service may be substantial. Route areas going from PSO to commercial operation may cause a worse situation for travellers. If possible, it may be better to keep such a route as a “0-bid” PSO.

PSO route areas may sometimes be split into subsidised PSO-routes and “0-bid” PSO routes, or even commercial, to increase total social benefits (i.e. Ørsta/Volda – Oslo from the North West Coast).

However, no firm conclusions might be drawn based on this numeric example for just one single route area. However, a satisfactory solution is clearly indicated for the routes in this example.

This paper offers a stepwise procedure for assessing PSO routes: Firstly, a framework for deciding upon LOS for air transport under PSO is presented. Secondly, we present a way of doing rough calculations of socio-economic profitability of PSO routes compared with best alternative transport. Finally, a model is presented which refines these calculations.

One limitation is that the traveller's value of the PSO service is measured in a rather crude way, with a simplification of the travellers' origin-destination pattern to comprise airport-airport travels only. This could be amended by using more detailed travel survey data. Another limitation is that the model is not suitable for optimising very complex PSO route structures. This might be a limited problem because there are not many dense PSO route networks. A third limitation is that the model in its current version does not take alternative transport modes (like road, rail or sea transport) into account. A general limitation is the choice of cost and demand functions, where other types of functions could be tested.

The numerical model is in a rather early stage. For future research, important steps are probably to test and refine the numerical model, and perhaps consider development possibilities in connection with general transport network models and heuristic models for vehicle routing problems. Another step could be to expand the tests of the LOS criteria to study more in detail how they could be applied in practice.

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Appendix

Theoretical model⁴

Variables and parameters

Endogenous variables

c	vehicle capacity (items/vehicle)
c_1	capacity of an aircraft
f	frequency (departures/time unit)
g	fuel consumption per vehicle kilometre ⁵
g_s	fuel consumption per stop (due to acceleration from stop)
k	number of vehicles employed
l	crew per vehicle
n	number of cars per vehicle (train case)
t	round-trip time
t_h	loading plus unloading time per item
u	unproductive time per roundtrip (turn-around time and waiting to depart)
y	the operation's service capacity (items/time unit)

Endogenous variables (input space)

v_0	number of vehicles allocated to the operation (size of fleet)
v_1	fleet capacity (items)
v_2	the operation's fuel consumption per time unit
v_3	handling capacity (items/time unit)

Exogenous variables

d	round-trip distance (sum of the distances of the links)
\bar{f}	highest allowable frequency under security regulations
s	number of stops used
t_s	time per stop (excluding loading and unloading time)
\underline{u}	lowest possible or allowable turn-around time
v	cruising speed (kilometres/time unit)

Parameters

The exogenous variables stem from route design (d and s), regulations (\bar{f} , \underline{u}), and vehicle design and/or regulations (v , t_s).

Parameters

ϕ load factor
 r, w, w_0, w_1, w_2, w_3 prices
 Denoting the average transport distance for each item by \bar{d} and

⁴ By H. Minken and K.S. Eriksen. See Eriksen and Minken (2007) for more details.

⁵ As an approximation, other distance-dependent inputs like oil, tyres and distance-dependent parts of maintenance and insurance are assumed to be proportional to fuel consumption, and the price of fuel is adjusted upwards to take that into account. Alternatively, g might have been considered a vector of inputs, but this would not really have provided much more scope for substitution.

the commonly used load factor by ϕ' , $\phi' = (d'/d)\phi$.

Empirical content – linear relationships

The empirical content of the model consists of the description of the operation and the assumptions given above, the exogenous variables and parameters, and the following linear relationships:

$$l = l_0 + l_1 c \quad (1)$$

$$c = c_0 + nc_1 \quad (2)$$

$$g = g_0 + g_1 c \quad (3)$$

$$r = r_0 + r_1 c \quad (4)$$

$$g_s = g_{s0} + g_{s1} c \quad (5)$$

Identities

$$t = \frac{d}{v} + t_s s + t_h \phi c + u \quad (6)$$

$$k = tf \quad (7)$$

$$y = cf \quad (8)$$

The production technology

Let X be the natural numbers N or the non-negative real numbers R_+ , as the case may be. We can then define k in a general way by

$$k = \min \left\{ x \in X \mid x \geq \left(\frac{d}{v} + t_s s + t_h \phi c + u \right) f \right\} \quad (9)$$

We also define the unproductive time \tilde{u} that satisfies the inequality in (9) with equality by

$$k = \left(\frac{d}{v} + t_s s + t_h \phi c + \tilde{u} \right) f \quad (10)$$

If k can be any non-negative real number, efficiency requires

$$k = \left(\frac{d}{v} + t_s s + t_h \phi c + \underline{u} \right) f \quad (11)$$

The difference between k in (11) and in (10) is

$$k^{\triangleright} = (\tilde{u} - \underline{u})f \quad (12)$$

k^{\triangleright} is the “excess inventory of vehicles” caused by the indivisibility of vehicles.

$$c_{\min} \leq c \leq c_{\max}, \quad f \leq \bar{f} \quad (13)$$

It might be noted that the existence of a minimum aircraft size or a maximum allowable frequency will generally invalidate the assumption of free disposability of inputs.

The cost functions

Abbreviations.

$$A = \frac{d}{v} + t_s s + \underline{u}, \quad B = dg_0 + sg_{s0}, \quad D = dg_1 + sg_{s1}, \quad E = t_h \phi$$

$$C = w_0 v_0 + w_1 v_1 + w_2 v_2 = w_0 k + w_1 ck + w_2 (Bf + Dy) \quad (14)$$

where $w_0 = r_0 + wl_0$, $w_1 = r_1 + wl_1$

C is to be minimised, given the production technology. Thus the problem is:

$$\begin{aligned} \text{Min}_f \quad & w_0 k + w_1 kyf^{-1} + w_2 (Bf + Dy) \\ \text{s.t.} \quad & k = \min \{ x \in X \mid x \geq Af + Ey \} \end{aligned} \quad (15)$$

In practical applications, a term T_f could be added to B to account for taxes or other payments per departure, and a term T_y could be added to D to account for taxes on seats or passengers or the like.

The solutions of these minimising problems are technically complicated and are not reproduced here.

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